Energy for portable sensor systems

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Group number:2

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Introduction

The project for today was designing a battery pack and a circuit to power the sensor system we have to build as the final project. First, we had to do research about different types of rechargeable batteries. We had to choose the right type of battery for our system. After that, we could design a circuit to measure the state of charge of the batteries we chose.

Analysis

Batteries

Lithium-Ion battery

Lithium-Ion (Li-Ion) batteries is a rechargeable battery, which is used massively in electronic devices, like laptops and smartphones. The main reasons for this is that they have a very big energy density, a minor memory effect and a slow loss of charge when not connected to a circuit. But how does this work?

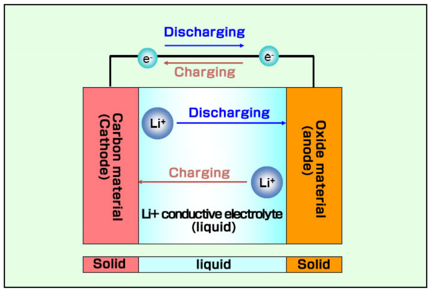
One single cell of a Li-Ion battery, consists out of different parts which are quite similar to other electric cells, namely an anode (negative electrode) which exists of lithium compounds, a cathode, (positive electrode) which contains graphite compounds, a separator (which avoids an short circuit but allows ions to pass through), a conductive plates, for example aluminium and copper and an electrolyte which is a solution of lithium salt.

When charging the battery, electrons from the charger will flow into the battery , and lithium ions will go to the other side. If a load is connected to the battery, the electrons will flow back to their initial side through wires connected to the battery, and lithium ions will go back through the separator to their initial position. depending on the used anode, the voltage produced by a single cell is about 3.6 to 3.8 volt.

Advantages/Disadvantages of a Lithium-Ion battery:

- + Very high energy density
- + Low self discharging when not connected to a load
- + Very low capacity lost as a result of charging an not-empty battery
- + High power
- + Eco-Friendly
- - Expensive
- - Chance of explosion as a result of overheating (regulators in the battery are added to avoid this)

Operating Principle of Lithium-ion Battery



Soruce: NEDO

Nickel-cadmium

Nickel-cadmium (NiCd) batteries were made on 1898,and are made in wide range of sizes.Their performance seems to be suitable in low temperature.They became popular in the middle of twentieth century.They used to be used a lot.

Small NiCd batteries are used for toys and portable electronics and middle size ones are used in wireless telephones and large ones in aircraft starting batteries.

The discharge rate of NiCd batteries varies by size.They can be charged at different rates,and the safe temperature is between -20C and 45C when using it and when it is near full charge the temperature is 45_50C.These batteries discharge themselves when are not used by 10% monthly and it is advisable to discharge them when do not wish to use them.

It seems that NiCd batteries have some advantages including not being damageable and higher energy density.They can tolerate deep discharge in long periods and they last longer in charge and discharge cycles.However,they have some disadvanatges compare to other batteries such as high cost, lower capacity and being toxic. The worst thing about NiCd batteries is decreasing internal resistance when the temperature increases.

Nickel metal-hydride battery

A nickel metal-hydride (NiMh) battery is very related to the already described Nickel-cadmium cell. It uses the same cathode, but a different anode. Instead of cadmium it uses a water absorbing alloy.

In daily life, we know NiMh batteries like ordinary batteries, because they come in standard formats, like AA and AAA. But they can be assembled to produce higher currents for applications like power sources for hybrid and RC cars.

There are some ways to control overcharging such as V-charging and T-charging. It means that when the battery is charged the voltage over,the voltage over the battery would drop and the charger should stop charging.Another method is measuring temperature.In this method the temperature is measured and befor being fully charged the energy converts to chemical energy;however after being fully charged the energy converts to temperature,and sensor should stop charging.

Generally, a NiMH battery contains more energy compared with a NiCd battery of the same size but produces less power. We will summarize all advantages and disadvantages of all batteries in a table.

Summarizing table

	Voltage (volt)	Charge/discharge times	Energy density Wh/kg	Power density W/kg	Operating temperature (degree celcius °)	Loss of charge per month at 25°C
Lithium-Ion	3.6-3.8	300+	140	180	14 to 122	3%
Nickel-Metal hydride	1.2	300+	60	175	-20 to 50	30%
Nickel-Cadmium	1.2	500+	50	200	-30 to 60	20%

Table 1. Summarizing table about the different battery types discussed in this analysis

Determining the State of Charge (SOC) of a battery

A complex, but very important part of a battery-powered system is the state of charge of the battery. There are several subsystems in the measurement. It largely consists of three parts.

Peukert's Law

Peukert's law is a simple model to describe the discharge time of a battery. It can be described using the following formula, where the first one gives the discharge time from fully charged to empty, and the second one gives the time remaining for any point between fully charged and empty.

$$H = \frac{C}{I^k}$$

$$t = H\left(\frac{C}{IH}\right)^k$$

t	Time to discharge [h]
H	Rated battery discharge time [h]
C	Rated battery capacity [AH]
I	Discharge current [A]
k	Peukert constant

'Rated' values can usually be found in the datasheet of the battery, or are given on the packaging. The rated battery discharge time (H) can also be calculated using the first formula. The Peukert constant depends on the battery. An ideal battery has a value of 1, but for practical batteries it is usually between 1.2 and 1.7. The value also increases as the battery gets older.

The pitfall, however, is that the formula assumes a constant discharge current. Since we don't have significant changes in current in the sensor system we are going to build in the final project, this model is still suitable.

Current measurement

The easiest way to find the current used by the circuit is adding a series resistor to the low side of the battery and feeding the voltage over the resistor into an operational amplifier buffer (figure 1).

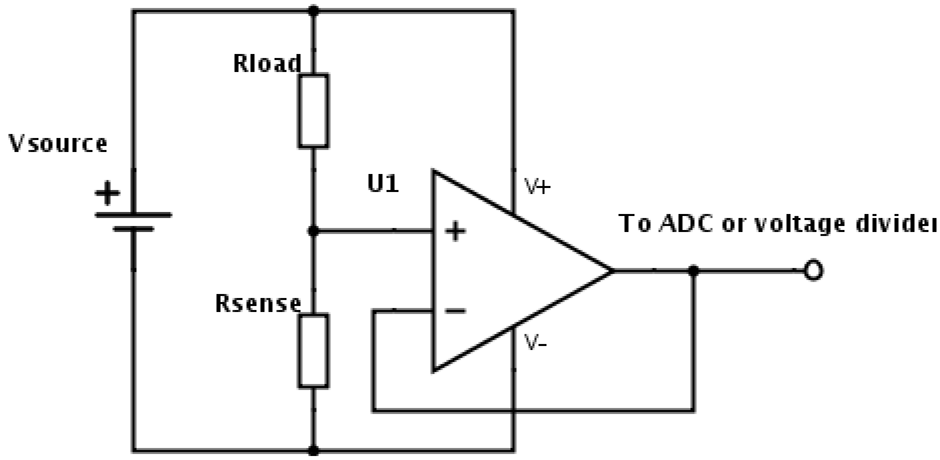


Figure 1. Low-side current measurement using a resistor and op-amp.

The output voltage is directly proportional to the current through the resistor, as we can see with Ohm's law ($U = IR$). We can feed the output of the opamp into an ADC (analog-digital converter) of the microcontroller that is used to process the sensor data. If the voltage range is not compatible with the input range of the ADC, a simple voltage divider will suffice. Since the ADC inputs are high impedance (around 100MOhm), there is no need to take the current here into account if we have proper resistors (not wasting too much energy, but still lower than the input resistor values). An opamp is used here, because attaching a voltage divider immediately will give the wrong results in many cases. The configuration is just a simple buffer.
The calculation/processing can be done in the microcontroller software.

Voltage measurement and a lookup table

We also measure the voltage over the battery. In the ROM of the microcontroller you can store a table of the discharge curve of the battery used. These tables can be made from graphs and are a direct translation from battery voltage to what percentage charge is left in the battery.

These curves are known for practically all battery types, as it depends on the chemistry of the battery.

However, we can only calculate the discharge time if we know the current. Using only the voltage is a much simpler solution, but it gives less information.

Results

Our choice for a battery is Lithium-Ion. Using three cells of these batteries we will have enough voltage to power a 5V microcontroller through a voltage regulator. Since the voltage regulator is already present on the Arduino board, it accepts a wide range of input voltages and we don't really have to worry about supplying a clean voltage to the board.

The final circuit is this:

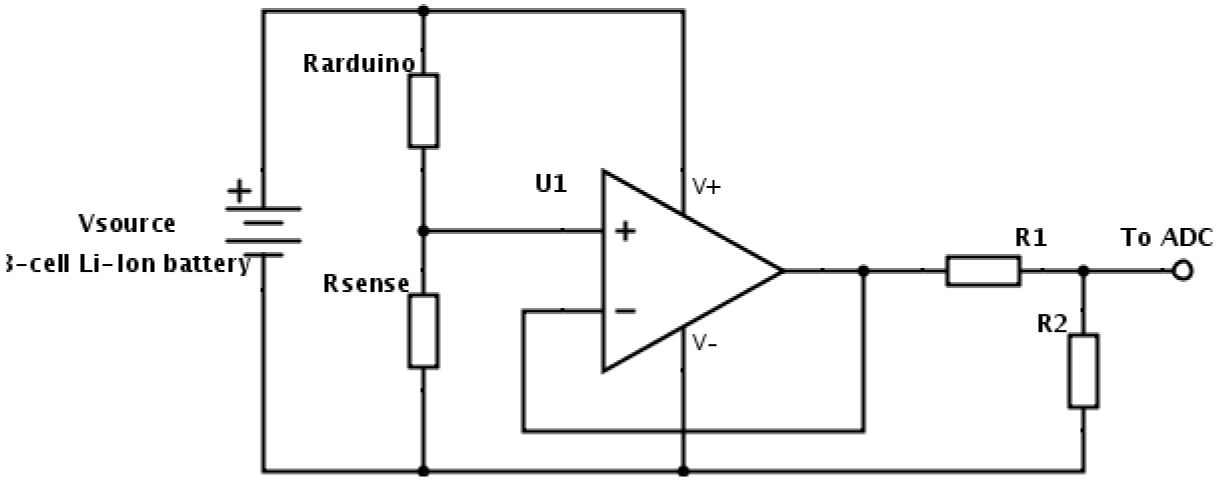


Figure 2. The final current measuring circuit, including a voltage divider.

The values of R_{sense}, R_1 and R_2 should be determined after we know the current used by the final sensor system. We only know the output voltage should be in a range of 0V to 5V (the input range of the Arduino/AVR built-in ADC). We do this by using a voltage divider with resistors R1 and R2. After we measured our current through the Ardruino using the ADC port, we can determine how our SOC is using the equations given in the analysis part.

Discussion

We have a more complex circuit than strictly necessary, but we had the peripherals available and it gives more insight in how long the battery will last. This information is very valuable in mission-critical systems, and just handy in regular devices.

Conlusion/Evaluation

Our conclusion is that we have now learnt about different types of batteries, discharge characteristics of diferent battery types, and how to determine the SOC of a battery. This is exactly the 'problem' we had to solve today, so it was pretty much a success.

However, it was a bit hard to get started because we didn't exactly know what information to look for and put in our report.

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